An Analysis of the Effects of Residential Photovoltaic Energy Systems on Home Sales Prices in California

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Lawrence Berkeley National Laboratory

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Effects of Residential PV Systems on Home Sales Prices in California

- Introductions
- Subject Overview
- Data Sources, Processing & Summary
- Methods
- Results
- Future Areas For Research
- Questions?

Project Report, Team, Funders

Project Report and Summary Completed in April 2011

- Available at: http://eetd.lbl.gov/ea/emp/re-pubs.html
- Webinar presentation to be posted soon

Project Team

- Ryan Wiser – LBNL – Principal Investigator/Project Manager
- Ben Hoen – LBNL – Principal Research Associate
- Pete Cappers – LBNL – Statistics Specialist
- Mark Thayer – SDSU – Econometric/Academic Specialist

Funders

- Solar Energy Technologies Program, U.S. DOE
- National Renewable Energy Laboratory
- Clean Energy States Alliance

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Motivation

Growing Market for Solar PV, Including Residential Applications

- State and federal incentive programs
- Rapidly declining cost of solar energy
- California the largest market historically in the U.S. approaching 100,000 PV homes

Homeowners/Builders May Be Hesitant To Invest Given Uncertain Sales Price Premiums

- PV system payback times may be longer than expected time of home ownership
- Disincentive to purchase/invest in PV if investment cannot be recouped

Appraisers/Assessors May Not Be Placing Value On PV

- Lenders may not be convinced that systems have a realizable premium at time of sale
- Or may at least be unwilling/unable to recognize that premium in appraisals/assessments

Precedent that Energy-Savings Investments Are Not Lost Upon Sale

- Energy bill savings via energy efficiency (EE) positively impact sales prices (next slide)
- Some empirical results suggest the same for PV (e.g., Farhar 2004/2008; Dastrop et al. 2010)
- Surveys of homeowners also suggest possibility of sales price premium
- Some evidence that new homes with PV sell faster than comparable non-PV homes

Limited Existing Research on PV Sales Price Impacts, But Data Available To Do More

- Large number of CA PV systems installed on homes, some of which have sold
- Access to large real estate datasets on home sales and characteristics

Literature on Impact of Energy Bill Savings On Sales Prices Implies Effects For PV

Partial list of available literature focused on energy efficiency

Authors	Sample Location	Sample Size	Test Used	Sale Price to Annual Savings Ratio*
Johnson & Kaserman (1983)	Knoxville, TN	1,317	utility bills	21:1
Dinan & Miranowski (1989)	Des Moines, IA	234	cost per ft2 to maintain 65°	12:1
Nevin & Watson (1998)	National - US	600 – 46,000	annual fuel bills	16:1-31:1
Nevin, Bender & Gazan (1999)	National - US	n.a.	compared to remodeling costs	20:1
Eichholtz, Kok & Quigley (2009)	National - US	122 (1,816)	energy use/savings	17:1-21:1

** E.g., 21:1 = a home's value increases by $21 for every $1 dollar/yr saved in energy costs*

Recent results for PV reinforce EE findings

Dastrop, Zivin, Costa & Khan (2010)	San Diego	~350,000 (279 PV)	PV Energy System	~3% premium

Project Summary

Background: PV may increase home sales prices due to energy bill savings and, potentially, from the cache of being environmentally friendly; a potential barrier to PV deployment exists if this value is not apparent and capitalized

Objectives: Build on available literature and test for effects by analyzing selling prices of homes with PV relative to comparable non-PV homes, also looking into variations by: (1) new vs. existing homes; (2) age of PV system; and (3) PV system size and home size

Scope: Use California residential home sales and PV system data and use hedonic and other econometric models to test effects directly

Importance: Findings may influence: (1) home owners considering installing PV or selling their home with PV already installed, (2) home buyers considering purchasing a home with PV already installed, and (3) new home builders considering installing PV on their production homes; also of relevance to the PV industry, as well as assessors, appraisers, and lenders

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Data Sources

1. **PV home addresses and system information** from three organizations in CA that have offered financial incentives to PV system owners in the state (from CEC, CPUC, SMUD)
2. **Real estate information** that was matched to those addresses and that also included the addresses of and information on non-PV homes nearby (from Core Logic, Inc.)
3. **Home sales price index data** that allowed regionally-differentiated (via zip codes) inflation adjustments to covert sales prices to 2009 dollars (from Fiserv)
4. **Locational data** to map the homes (from Sammamish)
5. **Elevation data** used as proxy for "scenic vista" (from CERES)

Data Processing

Dataset Acquisition Process

- PV home addresses and PV system information supplied by incentive providers (~42,000)
- "Matched" to known addresses by real estate data provider
- "Appended" with home and site characteristics (e.g., sqft, year built, acres, most recent and prior sale price and sale date)
- "Flagged" for homes that sold after PV was installed
- Real estate data provider also supplied information on ~150,000 comparable sales

Additional Dataset Cleaning Process

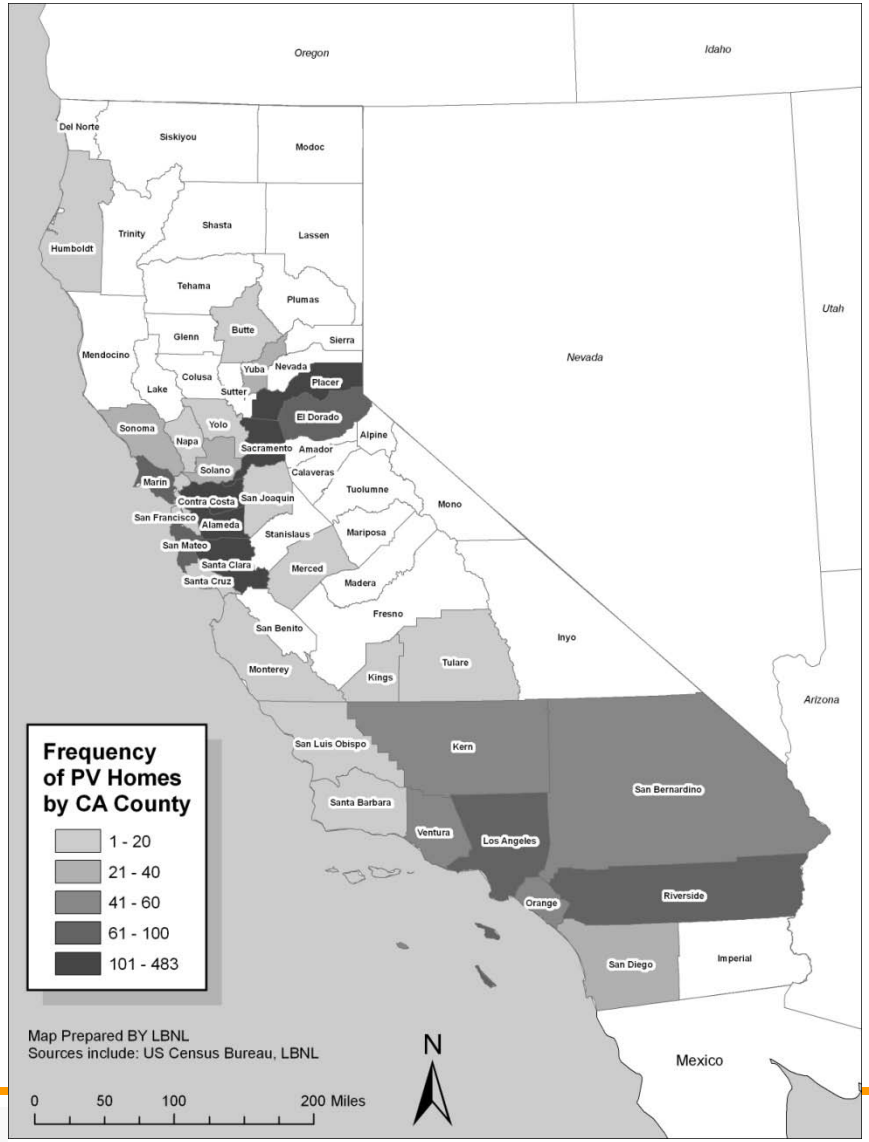
- Ensured that all data were fully populated
- Sales had to occur within time frame that price index data were available
- Additional data screens used to minimize impact of data errors, increase representativeness of results: e.g., adjusted sale price was within $85,000 and $2.5 million; lot less than 25 acres; PV system larger than 0.5 kW and smaller than 10 kW; etc.) [see full report]

Final Dataset Consists of 72,319 homes:

70,425 non-PV; 1,894 PV

(Homes sold between 1999 and 2009 with an average PV system size of 3.1 kW DC)

Home Sales Data Are Arrayed Across Geography, Home Type, Utility, and Time



Home Type	Non-PV	PV	Total
New Home	26,938	935	27,873
Existing Home	43.487	897	44,384

Utility	Non-PV	PV	Total
pge	36,137	945	37,082
sce	14,502	340	14,842
sdge	8,191	106	8,297
smud	11,393	498	11,891
other	202	5	207

Sale Year	Non-PV	PV	Total
1999-2001	1,824	11	1,835
2002	6,278	37	6,315
2003	8,783	63	8,846
2004	10,888	153	11,041
2005	10,678	168	10,846
2006	9,072	173	9,245
2007	8,794	472	9,266
2008	9,490	642	10,132
2009	4,618	175	4,793

Price Differences Exist Between PV and Non-PV Homes…

…But Other Underlying Differences Need To Be Accounted For

	Non-PV Homes					PV Homes				
Variable	*n*	Mean	Std. Dev.	Min	Max	*n*	Mean	Std. Dev.	Min	Max
sd2	70425	9/30/2005	793 days	1/7/1999	6/30/2009	1894	3/28/2007	622 days	8/1/2000	6/29/2009
sp2	70425	$ 584,740	$ 369,116	$ 69,000	$ 4,600,000	1894	$ 660,222	$ 435,217	$ 100,000	$ 3,300,000
asp2	70425	$ 480,862	$ 348,530	$ 85,007	$ 2,498,106	1894	$ 537,442	$ 387,023	$ 85,973	$ 2,419,214
lasp2	70425	12.9	0.6	11.4	14.7	1894	13.0	0.6	11.4	14.7
sqft_1000	70425	2.2	0.9	0.8	9.3	1894	2.4	0.9	0.8	11.0
ages2	70425	19	23.3	-1	108	1894	17.3	24.5	-1	104
ages2sqr	70425	943	1681	0	11881	1894	937	1849	0	11025
yrbuilt	70425	1986	23	1901	2009	1894	1989	25	1904	2009
acre	70425	0.3	0.8	0.0	24.8	1894	0.4	1.0	0.0	21.6
acrelt1	70425	0.2	0.2	0.0	1.0	1894	0.2	0.2	0.0	1.0
acregt1	70425	0.1	0.7	0.0	23.8	1894	0.1	0.9	0.0	20.6
elev	70425	424	598	0	5961	1894	414	584	0	5183
bgre_100	70425	0.0	1.2	-18.0	19.0	1894	0.2	1.3	-10.0	17.9
bath	70425	2.6	0.9	1	9	1894	2.9	1	1	7
avtotal	70425	$ 497,513	$ 359,567	$ 10,601	$ 3,876,000	1894	$ 552,052	$ 414,574	$ 23,460	$ 3,433,320
size	70425	0	0	0	0	1894	3.1	1.6	0.6	10.0

The Same Is True For Homes That Sold Twice ("Repeat Sales")

Repeat Sale Sample Subset Consists of 28,313 Homes:

27,919 non-PV; 394 PV

	Non-PV Homes				
Variable	*n*	Mean	Std. Dev.	Min	Max
sd1	27919	5/5/2001	1780 days	11/1/1984	12/11/2008
sp1	27919	$ 444,431	$ 287,901	$ 26,500	$ 2,649,000
asp1	27919	$ 488,127	$ 355,212	$ 85,398	$ 2,495,044
lasp1	27919	12.9	0.6	11.4	14.7
sd2	27919	5/14/2006	786 days	3/11/1999	6/30/2009
sp2	27919	$ 577,843	$ 371,157	$ 69,000	$ 3,500,000
asp2	27919	$ 481,183	$ 347,762	$ 85,007	$ 2,472,668
lasp2	27919	12.9	0.6	11.4	14.7
sddif	27919	1835	1509	181	7288
sqft_1000	27919	2.1	0.8	0.8	7.7
ages2	27919	23.6	22.7	0	108
ages2sqr	27919	1122.0	1775.0	1.0	11881.0
yrbuilt	27919	1982	23	1901	2008
acre	27919	0.3	0.7	0.0	23.2
acrelt1	27919	0.2	0.2	0.0	1.0
acregt1	27919	0.1	0.6	0.0	22.2
elev	27919	426	588	0	5961
bgre_100	27919	0.0	1.3	-17.7	19.0
bath	27919	2.5	0.8	1	9
avtotal	27919	$ 498,978	$ 360,673	$ 35,804	$ 3,788,511
size	27919	0	0	0	0

PV Homes				
n	Mean	Std. Dev.	Min	Max
394	11/22/1999	1792 days	11/30/1984	1/7/2008
394	$ 492,368	$ 351,817	$ 81,500	$ 2,500,000
394	$ 645,873	$ 417,639	$ 110,106	$ 2,339,804
394	13.2	0.6	11.6	14.7
394	1/9/2007	672 days	8/1/2000	6/29/2009
394	$ 800,359	$ 489,032	$ 121,000	$ 3,300,000
394	$ 666,416	$ 438,544	$ 91,446	$ 2,416,498
394	13.2	0.6	11.4	14.7
394	2605	1686	387	7280
394	2.2	0.8	0.8	5.3
394	34.6	25.6	1	104
394	1918.0	2336.0	4.0	11025.0
394	1972	26	1904	2008
394	0.5	1.4	0.0	21.6
394	0.2	0.2	0.0	1.0
394	0.2	1.3	0.0	20.6
394	479	581	3	3687
394	0.1	1.6	-5.5	17.9
394	2.6	0.9	1	7
394	$ 682,459	$ 478,768	$ 51,737	$ 3,433,320
394	4.03	1.94	0.89	10

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The Analysis Primarily Relied On Hedonic Regression Models

(A Total of 21 Models Were Used)

Linear regression, absorbing indicators

Number of obs = 72319
F(48, 71436) = 1295.80
Prob > F = 0.0000
R-squared = 0.9338
Adj R-squared = 0.9330
Root MSE = .16291

lasp2	Coef.	Robust Std. Err.	t	P>|t|	[95% Conf.	Interval]
size	.0121235	.0015462	7.84	0.000	.009093	.015154
bgre_100	.0029179	.0007654	3.81	0.000	.0014177	.0044182
sqft_1000	.2529623	.0013884	182.19	0.000	.250241	.2556837
acre	.0156419	.0023458	6.67	0.000	.0110441	.0202398
lt1acre	.4162471	.0086814	47.95	0.000	.3992316	.4332625
ages2	-.0038999	.0002029	-19.22	0.000	-.0042976	-.0035023
ages2sqr	.000026	2.52e-06	10.31	0.000	.000021	.0000309
syq2						
19991	.0398746	.0263051	1.52	0.130	-.0116833	.0914325
19992	.0671571	.0165078	4.07	0.000	.0348018	.0995124
19993	.0573857	.0195732	2.93	0.003	.0190222	.0957492
19994	.0236605	.0202137	1.17	0.242	-.0159583	.0632794
20001	.0166673	.0213889	0.78	0.436	-.0252548	.0585894
20002	.0289411	.0204155	1.42	0.156	-.0110732	.0689554
20003	-.0128151	.0153382	-0.84	0.403	-.0428779	.0172477
20004	-.0274952	.0222013	-1.24	0.216	-.0710098	.0160194
20011	.0503023	.0132198	3.81	0.000	.0243914	.0762131
20012	.048385	.0104792	4.62	0.000	.0278458	.0689241
20013	.0620939	.0083202	7.46	0.000	.0457863	.0784014
20014	.0361634	.0091375	3.96	0.000	.018254	.0540729
20021	.0417675	.0063809	6.55	0.000	.029261	.0542739
20022	.0446636	.0059361	7.52	0.000	.0330289	.0562983
20023	.0243725	.0060348	4.04	0.000	.0125444	.0362006
20024	.0004223	.00594	0.07	0.943	-.0112201	.0120646
20031	-.0027968	.0058906	-0.47	0.635	-.0143423	.0087487
20032	.008659	.0054321	1.59	0.111	-.001988	.019306
20033	.0016728	.0054418	0.31	0.759	-.008993	.0123386
20034	-.0203479	.0057849	-3.52	0.000	-.0316863	-.0090095
20041	-.0253306	.0057083	-4.44	0.000	-.0365188	-.0141424
20042	-.0111829	.0052812	-2.12	0.034	-.0215341	-.0008317
20043	-.0230003	.005369	-4.28	0.000	-.0335235	-.012477
20044	-.0445825	.0054261	-8.22	0.000	-.0552175	-.0339474
20051	-.0320784	.0055422	-5.79	0.000	-.0429412	-.0212156
20052	-.038759	.005393	-7.19	0.000	-.0493293	-.0281886
20053	-.0448033	.0052673	-8.51	0.000	-.0551273	-.0344793
20054	-.0603053	.0055454	-10.87	0.000	-.0711743	-.0494364
20061	-.0730199	.0055484	-13.16	0.000	-.0838946	-.0621451
20062	-.0608224	.005417	-11.23	0.000	-.0714397	-.0502051
20063	-.0823852	.0055843	-14.75	0.000	-.0933303	-.07144
20064	-.1076038	.0056571	-19.02	0.000	-.1186917	-.096516
20071	-.0889282	.0057695	-15.41	0.000	-.1002364	-.0776199
20072	-.0528473	.0057909	-9.13	0.000	-.0641975	-.041497
20073	-.0400269	.0057946	-6.91	0.000	-.0513843	-.0286694
20074	-.0384468	.0057269	-6.71	0.000	-.0496715	-.0272221
20081	-.0079877	.0059914	-1.33	0.182	-.0197309	.0037554
20082	.0416887	.0056778	7.34	0.000	.0305604	.0528171
20083	.0407342	.0056339	7.23	0.000	.0296918	.0517767
20084	.021192	.0061468	3.45	0.001	.0091443	.0332397
20092	.0280948	.0062267	4.51	0.000	.0158904	.0402991
_cons	12.7022	.0104964	1210.15	0.000	12.68162	12.72277
blkgrp	absorbed					(835 categories)

Controlling Variables:

Home and Site Characteristics: Size of the home (in square feet), size of the parcel (in acres), age of the home, relative elevation of the home

Location Fixed Effects: Census Block Group (or Subdivision)

Market Fixed Effects: Year and quarter in which sale occurred

Variables of Interest:

If the home has a PV system

The size of the PV system

Different Model Variations Used To Explore Various Hypotheses/Ensure Robust Results

Fixed Effect Hedonic Models: These models assume that sale price effects related to PV are constant (i.e. fixed), on a percentage basis relative to sales prices, across all homes regardless of PV system size and sales price

Continuous Effect Hedonic Models: These models assume that sale price effects related to PV, on a percentage basis relative to sales prices, are linearly correlated (i.e., continuous) with the size of the PV system (i.e., not fixed)

PV-Only Hedonic Model: This model, which only includes homes with PV systems (and does not include non-PV comparable homes), tests if price differences between PV homes can be explained by the size of the PV system

New and Existing Home Hedonic Models: These models test whether PV sale price effects are similar for *new* and *existing* homes

Difference-in-Difference (using Repeat Sales) Models: Using a set of homes that sold more than once and comparing the adjusted sale price of the first sale (without PV) to the second sale (with PV), while controlling for inherent differences between PV and non-PV homes and inflation, sale price differences driven by PV for *existing* homes can be explored in an alternative way

Age of PV System for Existing Homes Hedonic Models: These models explore if sale price premiums from PV are related to the age of the PV system at the time of sale

Returns-to-Scale Hedonic Models: These models explore whether sale price premiums from PV are non-linear to the size of the PV system or are impacted by the size of the home

Example: Continuous Effect Hedonic Model

$$\ln(P_{itk}) = \alpha + \beta_1(T_t) + \beta_2(N_k) + \sum_a \beta_3(X_i) + \beta_4(PV_i \cdot SIZE_i) + \varepsilon_{itk}$$

where

P_{itk} represents the inflation adjusted sale price for transaction *i*, in quarter *t*, in block group *k,*

α is the constant or intercept across the full sample,

T_t is the quarter in which transaction *i* occurred,

N_k is the block group in which transaction *i* occurred,

X_i is a vector of *a* home characteristics for transaction *i* (e.g., acres, square feet, age, etc.),

PV_i is a fixed effect variable indicating if a PV system is installed on the home in transaction *i*,

$SIZE_i$ is the size (in kW, DC) of the PV system on the home in transaction *i*,

β_1 is a parameter estimate for the quarter in which transaction *i* occurred,

β_2 is a parameter estimate for the block group in which transaction *i* occurred,

β_3 is a vector of parameter estimates for home characteristics *a*,

β_4 is a parameter estimate for the percentage change in sale price for each additional kW added to a PV system,

ε_{itk} is a random disturbance term for transaction *i*.

Difference-in-Difference (Using Repeat Sales) Model

	Pre PV	Post PV	Difference
PV Homes	PV_1	PV_2	$\Delta PV = PV_2 - PV_1$
Non-PV Homes	NPV_1	NPV_2	$\Delta NPV = NPV_2 - NPV_1$
			$DD = \Delta PV - \Delta NPV$
1 and 2 denote time periods			

$$\ln(P_{itk}) = \alpha + \beta_1(T_t) + \beta_2(N_k) + \sum_a \beta_3(X_i) + \beta_4(PVH_i) + \beta_5(Sale2_i) + \beta_6(PVS_i) + \varepsilon_{itk}$$

where

PVH_i is a fixed effect variable indicating if a PV system is or will be installed on the home in transaction *i*,

$Sale2_i$ is a fixed effect variable indicating if transaction *i* is the second of the two sales,

PVS_i is a fixed effect variable (an interaction between PV_i and $Sale2_i$) indicating if transaction *i* is both the second of the two sales and contained a PV system at the time of sale,

α is the constant or intercept across the full sample, and represents the base value of non-PV homes as of the initial sale (i.e., "NPV_1" from Table 1),

β_4 is a parameter estimate for homes that have or will have PV installed (i.e., "$PV_1 - NPV_1$"),

β_5 is a parameter estimate if transaction *i* occurred as of the second sale (i.e., "ΔNPV"),

β_6 is a parameter estimate if transaction *i* occurred as of the second sale and the home contained PV (i.e., "ΔPV – ΔNPV" or "DD"), and

all other terms are as were defined in equation on previous slide.

Various Tests Used To Reduce Potential Omitted Variable and Selection Bias

- **Coarsened Exact Matched Models:** This matching technique identifies statistically identical non-PV homes in each block group for each PV home based on a set of characteristics that include: size of the home (in square feet); size of the parcel (in acres); number of bathrooms; age of the home at the time of sale; date the home sold; and elevation of the home. Because many homes do not have statistical matches, the resulting dataset is considerably smaller (13,329 homes, 1,465 of which are PV).
- **Combined Subdivision-Block Group Fixed Effects:** The base models use the census block group as the spatial control, but a subdivision delineation may be better because homes in the same subdivision may be more alike than homes delineated by the somewhat-more arbitrary block group. These models use the subdivision delineation where it is available, and otherwise use the block group.
- **Restricting Sale Date Differences to Five Years in the Difference-in-Difference (DD) Model:** In the base DD model the first and second sale can be separated by as many as 20 years, and the potential for changes to a home that are not reflected in the characteristics included in the model increases with time between sales. This model limits the time between the first and second sale to five years to reduce potential bias.

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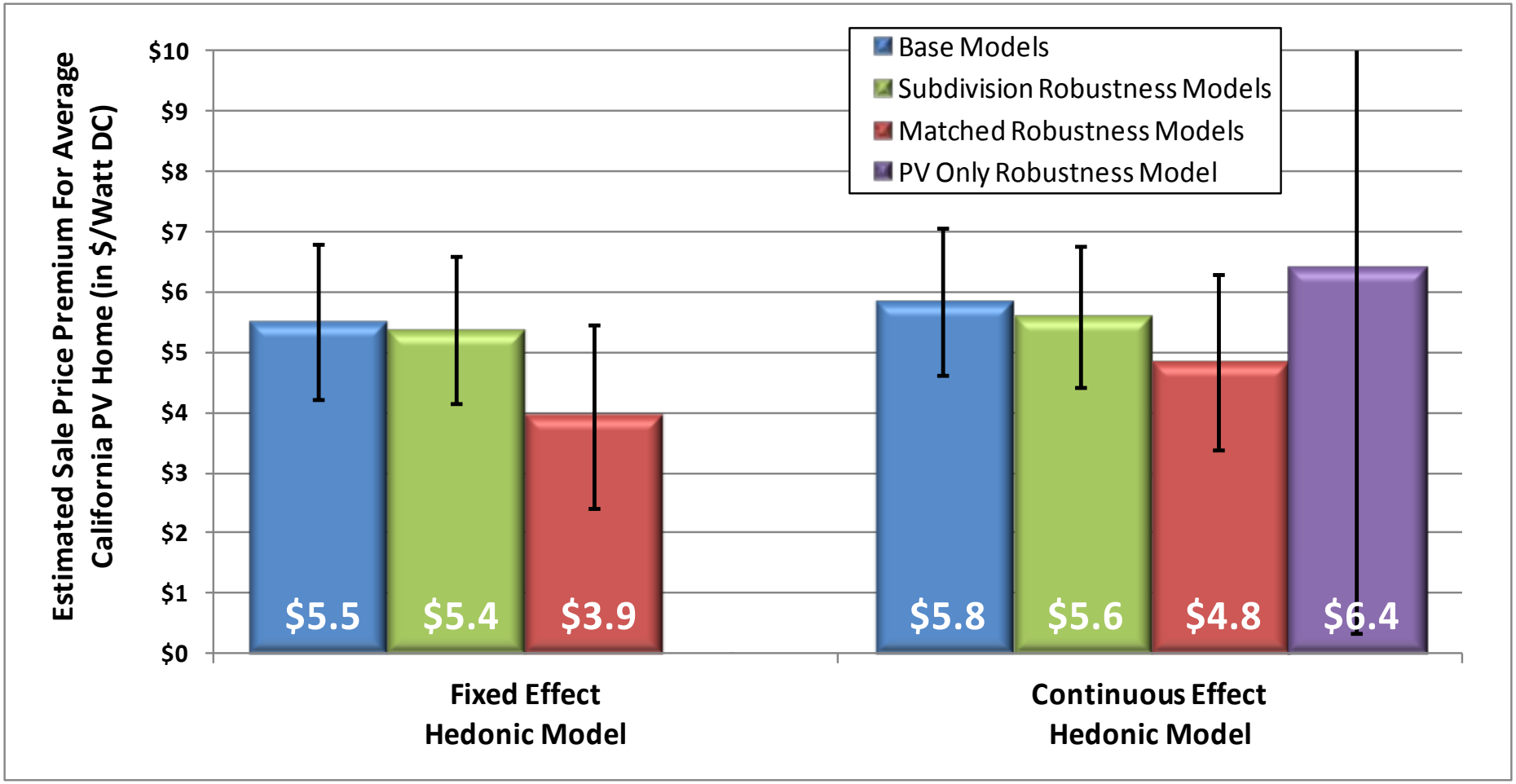
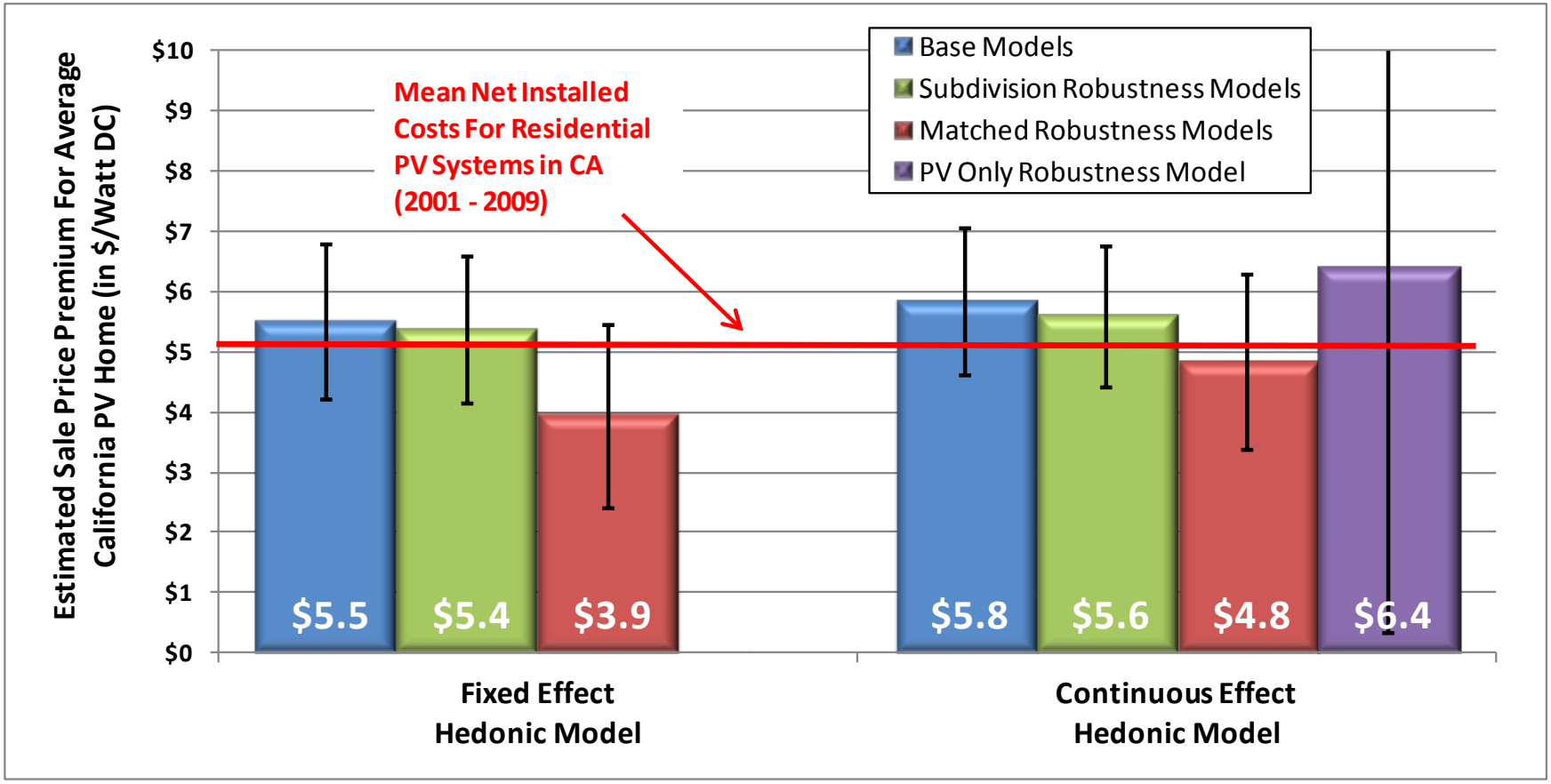
Model Performance Was Strong, Results Were Robust to Various Specifications

- Adjusted R^2 = 0.93 - 0.95
- Home and site characteristic effects were almost always statistically significant at above the 1% level, with coefficients in-line with other studies
- Coefficient estimates for home and site characteristics were generally quite stable across models

Estimated $/Watt (DC, STC) Premiums For The Full Sample Are Between $3.9 and $6.4

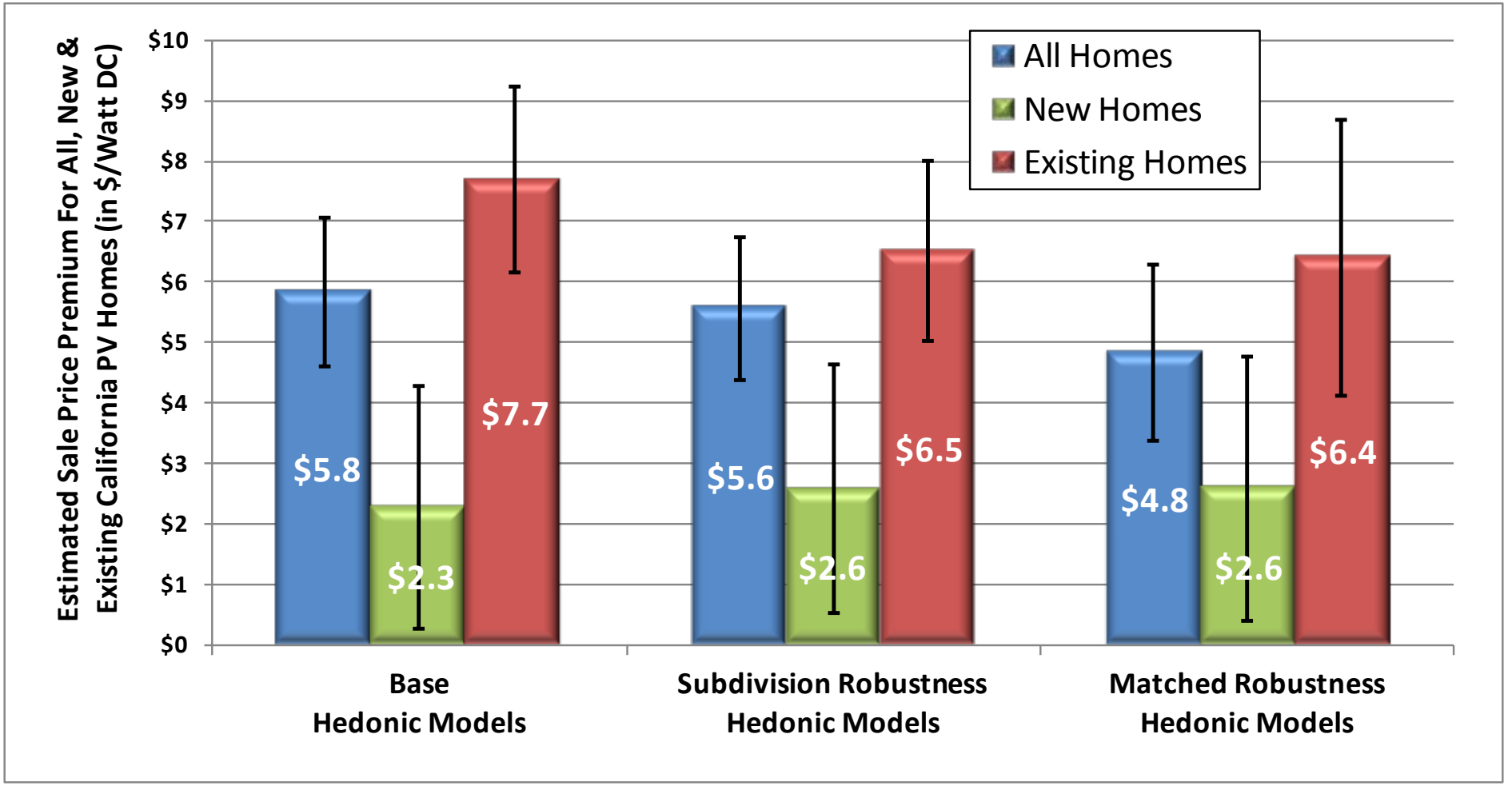


Buyers And Sellers Might Be Using Net Installed Costs As A Price Signal

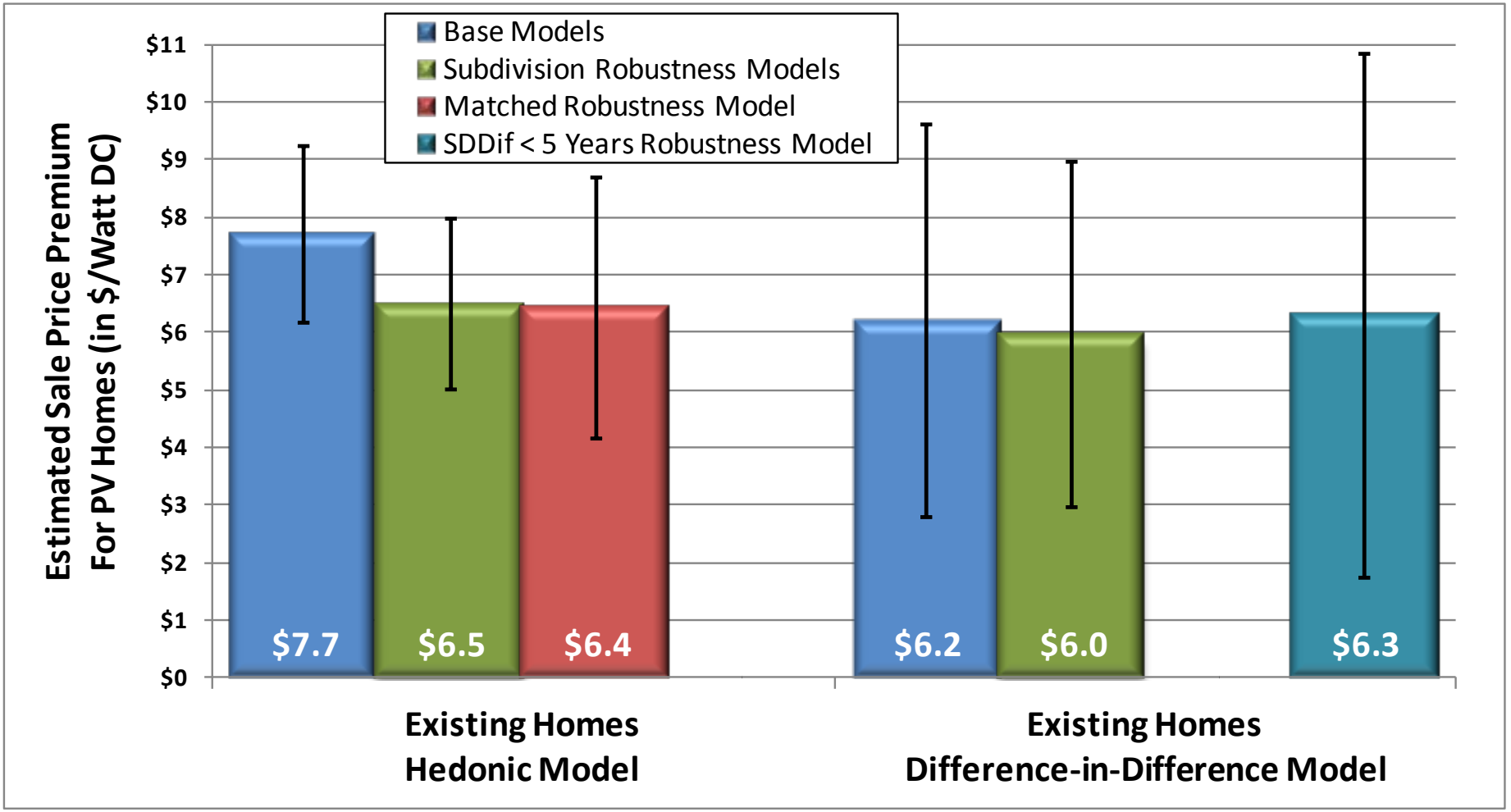


Net Installed Cost = Average cost of installing PV for a customer, after deducting available state/federal incentives

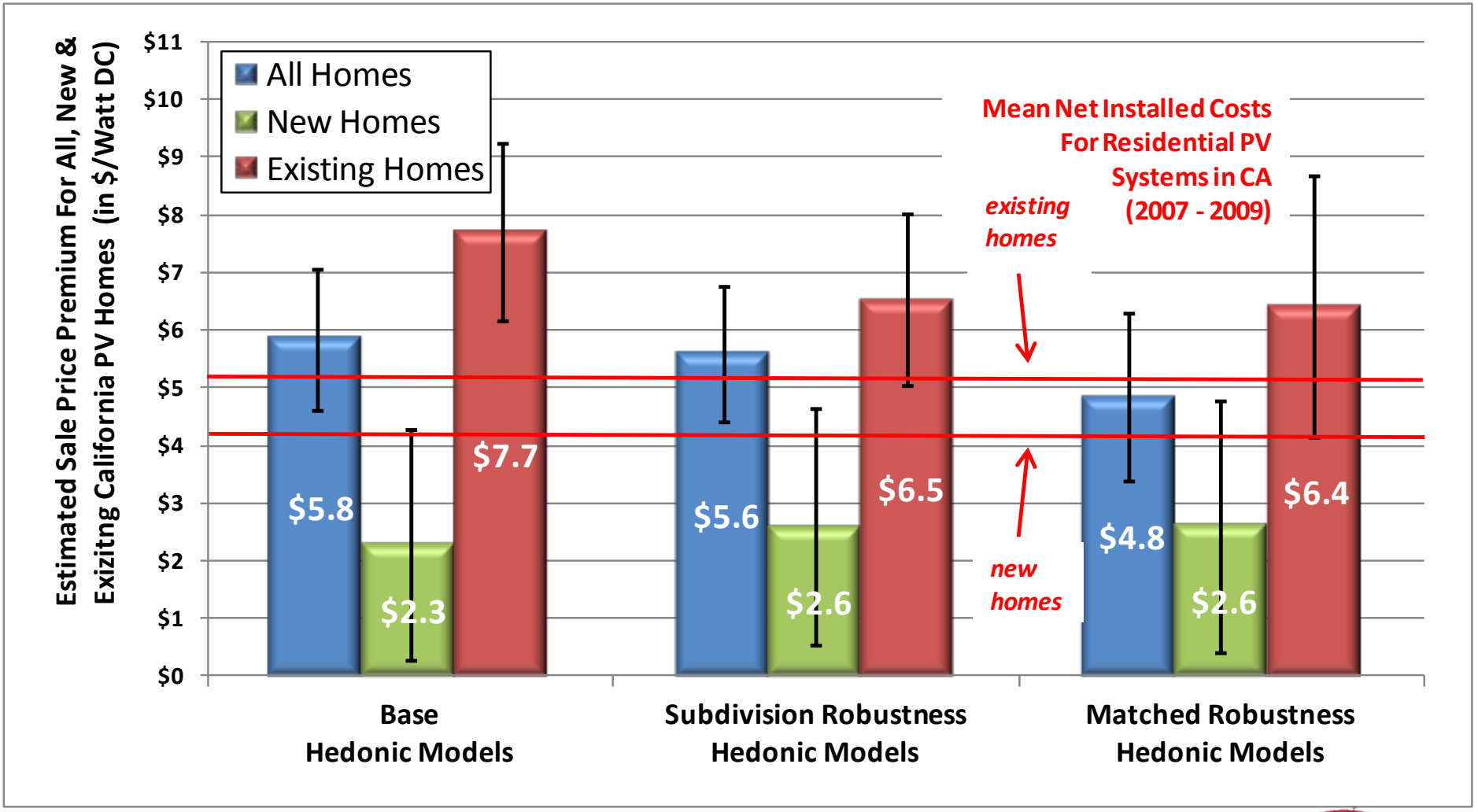
Large Differences In Premiums Were Found Between New and Existing Homes



For Existing Homes, Models Converge At Premium Of $6 to $6.5/Watt (DC)



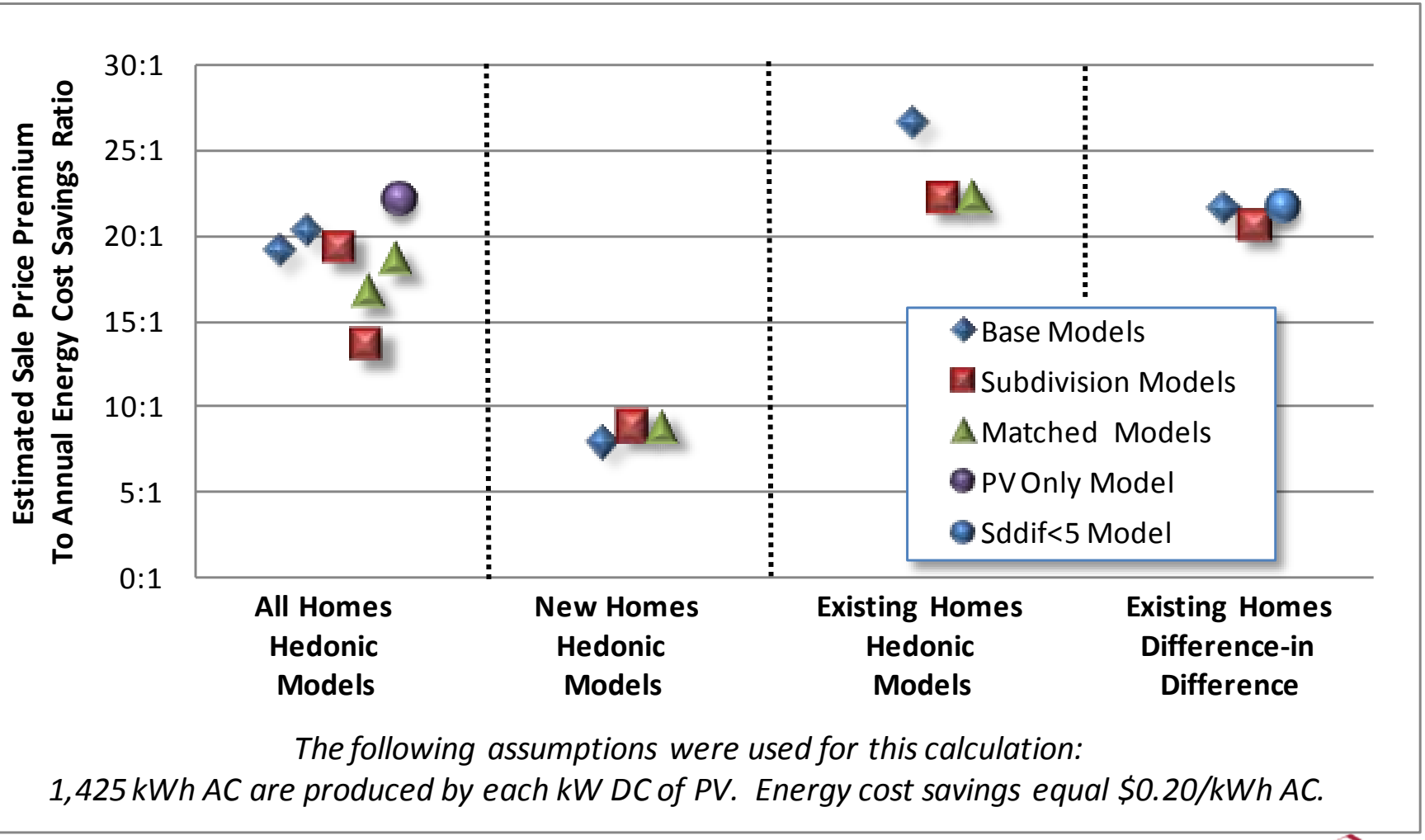
Differences Might Be Partly Explained By Disparity In Net Installed Costs



Disparities Might Be Explained By Other Factors Besides Net Installed Cost

New Homes		Existing Homes
Increased sales velocity?	←→	Highest price?
Sales agent less familiarity with PV?	←→	Homeowner more familiarity with PV?
Group PV with other features?	←→	Differentiate PV from other features?
Less expensive homes = less discretionary income?	←→	More expensive homes = more discretionary income?

Estimated Sale Price Premiums To Annual Savings Ratios ~20:1 For Existing Homes



The following assumptions were used for this calculation:
1,425 kWh AC are produced by each kW DC of PV. Energy cost savings equal $0.20/kWh AC.

Additional Results

- Evidence that older PV systems garner less of a premium than newer systems
- Lack of evidence that the size of the home influences the premium, all else being equal
- Lack of evidence that the relationship between size of the PV system and the premium is non-linear (i.e., no increasing or decreasing returns to scale)

Results Conclusions

- PV was found to have increased the average sales price of homes in CA historically (1999-2009)
- Overall average premiums (~$5.5/W, or $17,000 for 3.1 kW average system size in sample) have been in-line with historical net installed costs, at least for existing homes
- Average premiums were found to have been larger for existing homes than for new homes
- This difference may be partly explained by net installed costs, but also related to varying buyer/seller motivations (e.g., sales velocity)
- ~20:1 sales premium to annual bill savings ratio is supported, at least for existing homes, consistent with previous literature

Effects of Residential PV Systems on Home Sales Prices in California

- Introductions
- Subject Overview
- Data Sources, Processing & Summary
- Methods
- Preliminary Results
- Future Areas For Research
- Questions?

Variety Of Additional Research Areas Could Be Pursued (examples)

- **Larger, More Diverse Dataset:** The dataset used for this research only included sales prior to mid-2009 from California. Future research could include sales occurring later and from other parts of the country.
- **Explore Actual Energy Bill Savings:** For this research, PV system size was used as a proxy for energy cost savings. Future research might include a better assessment of actual/estimated savings on a house-by-house basis to explore the relationship to selling price premiums and if, and when, sale prices also include a green cache component.
- **Explore Actual Net Installed Costs and System Characteristics:** For this research, estimated average net installed costs were used as a comparison point separate from the underlying analysis itself. Future research could include actual net installed costs to assess whether there is a relationship to selling price. Variations in rack-mounted vs. BIPV, 3rd party vs. customer-owned PV, the efficiency of the home, and other system and home characteristics might also be explored.
- **Explore *New* vs. *Existing* Homes:** It is not entirely clear why the price difference exists between *new* and *existing* homes among the sample used here. These drivers could be further explored, ideally with a larger sample of homes. Future research might also include builder/homeowner surveys, and an analysis of sales velocity.

Questions?

To Ask a Question:

Please type your question into the Chat Box of the ReadyTalk Viewer.

Questions will be answered in the order they are received.

Or contact the authors:

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Or refer to the report, 2-page summary, or presentation

- http://eetd.lbl.gov/ea/emp/re-pubs.html